Science Education International
Vol. 17, No. 4, December 2006, pp. 241-251

International Council of Associations in Science Education

The Implications of Curricular Reform for Secondary Science Teacher Education in England

PAUL ELLIOTT (p.elliott@warwick.ac.uk)
Institute of Education, University of Warwick, UK

ABSTRACT *The purpose of science education has long been debated. Attempts to define scientific literacy provided a focus for the debate and have been driven by the widely held view that science education should stimulate behavioural changes to ensure a sustainable future. It has also led researchers to try and determine what makes science purposeful for students, and what scientific knowledge and skills adults need. The curricular reforms proposed as a result of these processes attempt to challenge practitioners' established views of secondary science education. It is expected that the reforms will only produce the desired effects, if practitioners are provided with different levels of support and professional freedom sufficient to enable them take ownership of the change in paradigm. Initial teacher training, undergraduate science programmes and even the design of science classrooms, all have a part of play in bringing about successful reform.*

KEY WORDS: *Science curriculum, scientific literacy, teacher education*

Introduction

Science education has always had an identity crisis. Its purpose has been the subject of debate, since schools first began teaching the sciences. One focus of the debate has been the concept of *scientific literacy*, its meaning and its implications for the science curriculum. This article examines the debate from an international perspective and considers its recent influence on curricular reform in England. Many aspects of the debate are relevant to the 5-16 curriculum, but this article will focus on the implications for the final years of compulsory schooling (Key Stage 4) and the need to win the support of practitioners for a change in approach, which has been driven by research findings and academic debate. It will also consider the implications for initial and continuing teacher education.

With science a compulsory part of the school curriculum for 5-16 year olds in England and Wales, and the requirement to understand and practice scientific method embedded within the national curriculum, the 1990's could have been a time for those who had been seeking reform of science education to sit back and enjoy their success. A requirement for inquiry-based teaching methods was embedded in the curriculum and part of the assessment regimes. Constructivist approaches were being promoted in initial teacher education and continuing professional development. However, many thought that these advances, while welcome, were not yet delivering the science education that was really needed (Millar, 1996; Soloman, 1997). The problem was that science education in the UK

was aiming to do two things. First, to train a minority in science, so that they were equipped to study it to higher levels; and second, to provide something of relevance to the needs of the majority, what is often now referred to as *scientific literacy*. The first of these aims still took precedence at the start of the twenty-first century, with a curriculum too content-laden for the second aim to be achieved, a problem recognised in a House of Lords' Select Committee report *Science and Society* (2000). As Murphy, Beggs, Hickey, O'Meara, and Sweeney (2001) explained: "In the UK, it has also been recognised that there is still an overemphasis on content in the school science curriculum. Much of this content is isolated from the contexts which could provide relevance and meaning" (p. 192). With two, apparently conflicting aims, much of the debate in recent years focused on the question of what a relevant science curriculum should look like, indeed, what the purpose of science education is.

The Scientific Literacy Debate as a Factor in Curricular Reform

The term *scientific literacy* was first used in the late 1950's by educationalists in the United States, such as Hurd (1958) and McCurdy (1958). The term was less widely used in the UK than the phrase *Public Understanding of Science,* but they shared similarities of meaning. Over the last decade or more, the meaning and significance of the term scientific literacy has received more attention from science educationalists (Hard, 1998; Fensham & Harlen 1999; Hodson, 1999, 2003; Kolstø, 2001; Fensham, 2004) and has been a driver of curriculum reform internationally. Fensham (2004) refers to scientific literacy as the "shorthand new slogan for the goal of the new science curricula" (p. 10). However, there is little precise agreement on what scientific literacy is and, rather like Fensham, Bybee (1997) suggested that it is best thought of as a broad concept that can act as a rallying call.

The use of the word *literacy* suggests that *scientific literacy* should be seen as a desirable set of skills and attainments, in much that way that literacy and numeracy are seen as desirable outcomes of education. Many authors have tried to define scientific literacy in these terms, but it is not a simple task. Hurd (1998) used twenty-five points when he tried to encapsulate the features possessed by a scientifically literate person. Many of these features relate to an understanding of the nature of science, but also how science interacts with and is used by society. However, as it is defined, scientific literacy can be considered as a socially important attribute. Millar, Osborne and Nott (1998) suggested that someone who lacks understanding of the contribution that science makes to ideas about the universe is an *outsider,* excluded from common elements of culture, in a similar way to someone who is illiterate. Referring to the nature of science, they stated that "The sciences... offer a knowledge that can be relied upon. This reliable knowledge tells us that things are often not as they seem" (p. 20). They go on to make ten recommendations that address the problems posed by the need for a secondary curriculum, which can attain a scientifically literate populace, as well as meet the requirements of the next generation of scientists.

DeBoer (2000) reviewed the many attempts to define scientific literacy and concluded that they could be summarised as identifying nine main goals, which he placed under the following headings:

- Teaching and learning about science as a cultural force in the modern world.

- Preparation for the world of work.
- Teaching and learning about science that has direct application to everyday living.
- Teaching students to be informed citizens.
- Learning about science as a particular way of examining the natural world.
- Understanding reports and discussions of science that appear in the popular media.
- Learning about science for its aesthetic appeal.
- Preparing citizens who are sympathetic to science.
- Understanding the nature and importance of technology and the relationship between technology and science.

He goes on to point out that one of the difficulties that authors have encountered when trying to define scientific literacy, and then reform science education accordingly, is that scientific understanding is open-ended and ever-changing. This dynamic nature of science, plus the breadth of attributes encapsulated by the term scientific literacy, makes it very problematic to determine when scientific literacy has been achieved. Fensham (2004) questions whether the term refers to "a scientific equivalent to the basic beginnings of reading and writing…or whether is it about becoming literate in science in the sense that persons with a considerable mastery of the use of words are said to be literate?" (p. 10). It is certainly much harder to measure an individual's scientific literacy than it is their literacy or numeracy. DeBoer (2000) makes the important points that because science grows and moves on, scientific literacy is something that the adult population could be expected to achieve and that, while the acquisition of scientific literacy should start in school, it should be in such a way that students should be inspired to take an interest in science, formally or informally, in the future.

Thus, we should not expect students leaving school to be scientifically literate, but that they should be interested enough in science and the associated socio-scientific issues to stay informed as adults. In other words, the quest for scientifically literate citizens is a life-long learning issue. This makes scientific literacy distinct from literacy and numeracy in that the education system can aspire to produce students who have a level of literacy and numeracy at the end of their schooling that will serve them well in their adult lives, whether or not they develop the associated skills further. Perhaps scientific literacy is fundamentally different to either literacy or numeracy, because of social norms. Whereas most adults need to show some level of skill with words and numbers, it is possible to have a highly successful professional and private life without being scientifically literate beyond a capability to cope with everyday technology and health matters (Atkin & Helms, 1993; Fensham, 2004). The cultural status of scientific knowledge and understanding in the adult population serves to reinforce this view. Perhaps, the term *scientific literacy* is misleading, because it suggests something equivalent to literacy and numeracy, when it is not? Doubts about the usefulness of the term *scientific literacy* led Fensham (2004) to suggest *science for citizenship,* as a more accurate rallying call for curriculum reform.

Even if scientific literacy may not be essential for the individual, might it be

essential for Society to be composed of scientifically literate individuals? Kolstø (2001) believes that the laity need knowledge of science and the characteristics of scientific knowledge in order to promote their points of view on socio-scientific matters and participate in democracy; what Fensham (2004), calls the "democratic assumption" (p. 10). This view is exemplified by Schreiner and Sjøberg (2003) who suggested that "development of environmentally active citizens is crucial for the future of our society and for the well-being of every individual" and that "Environmental protection relies on full participation of all actors in society, and is dependent on an aware and informed population respecting the values of a sustainable development" (p. 2). Hodson (2003) went even further, suggesting that scientific literacy is essential to bring about a shift in values from an anthropocentric view of the world to a biocentric or planetary-centric one. He made a very powerful case based on the threat to the future of the planet from economic globalisation, increasing production, and unlimited expansion. He called for changes in pedagogy to promote active, politicized citizens "who will fight for what is right, good and just; people who will work to re-fashion society along more socially-just lines; people who will work vigorously in the best interests of the biosphere" (p. 660). To this end, he advocated a politicized, issues-based science curriculum addressed at four levels of increasing sophistication:

- Level 1: Appreciating the societal impact of scientific and technological change, and recognising that science and technology are, to some extent, culturally determined.
- Level 2: Recognising that decisions about scientific and technological development are taken in pursuit of particular interests, and that benefits accruing to some may be at the expense of others. Recognising that scientific and technological development are inextricably linked with the distribution of wealth and power.
- Level 3: Developing one's own views and establishing one's own underlying value positions.
- Level 4: Preparing for and taking action.

As Hodson (2003) conceded, this is a formidable task and he stated that traditional models of curriculum development and teacher education will not be sufficient to bring about the change needed. While most authors do not state the case as radically as Hodson (2003), there is a widespread belief that science education needs to do something it has not yet achieved.

Teachers' Views of Science Education and Curriculum Reform

Levinson and Turner (2001) asked over three hundred science teachers in England what they thought the purpose of science teaching was. Almost half their respondents felt that science teaching should be *value free* and that it depended upon the delivery of facts. Indeed, some felt that the integrity of the subject might be undermined if social and ethical matters were included in their lessons. Their concerns appear to have centred on the role of talk in the classroom, the time taken to incorporate value-related discussions in lessons, and the risk that students may become so emboldened as to question factually-based content as well. These concerns are despite the fact that the National Curriculum for Science (1999) at

Key Stage 4 (14-16 years) already states that "Pupils should be taught to consider the power and limitations of science in addressing industrial, social and environmental questions, including the kinds of questions science can and cannot answer, uncertainties in scientific knowledge and the ethical issues involved, something that can surely only be achieved through the effective use of classroom talk" (p. 37) Levinson (2001) stated that this aspect of the curriculum makes unrealistic assumptions about the way that science teachers perceive their role and the skills that they can draw on. He proposed that it may be possible to develop a curriculum in which science teachers provide "greater knowledge of the science concepts" and collaborating humanities teachers, who are more at home with controversy' deal with the socio-scientific issues" (p. 101). Unfortunately, this model reinforces the stereotype of the scientist as the value-free person who is either not interested in, or unaware of the ethical and cultural implications of their subject, reinforcing stereotypical views held by pupils, as identified by Schibeci and Lee (2003). The alternative to Levinson's suggestion is to better prepare new teachers to take on the wider classroom role of scientists as citizens, and to provide support for experienced teachers as they make changes to the way they see their role and acquire a wider range of teaching skills.

Leach (2002) investigated science teachers' views on the future of the secondary science curriculum by seeking their opinions on the relevance of the curriculum for those who study it, its content, and the extent to which it motivates learners and teachers. To stimulate discussion, teachers were provided with pairs of statements, each representing polarised views on the issues, in advance of focus group meetings. He found that teachers broadly welcome reform of the curriculum to make it more appropriate for all students, and not just for those intending to follow a science-based route into higher education and careers. They also welcomed more flexible provision at Key Stage 4 (14-16 years) to meet the needs of different students, particularly those of the most and least able, and have an appetite for more professional autonomy in providing this flexibility. Whilst Leach (2002) found that some teachers had concerns about the curriculum losing rigour, and there was not full agreement on how the curriculum should be revised, there was not the degree of scepticism that Levinson (2001) found in his survey.

It is clear that there will be powerful forms of inertia to overcome, if a new paradigm of science education is to be formed. Some teachers are comfortable with the traditional paradigm, and may even love the way they teach science with its emphasis on facts and practical apparatus. Why should they change when they cannot see the purpose of that change, lack confidence to implement it, or feel under pressure to *play it safe* in a culture of inspection? Why should they risk adopting strategies that may produce students who are too assertive and too willing to question the way they are being taught? Fears of this sort should not be underestimated and nor should teachers' lack of belief in their individual ability to bring about change. Thrupp, Mansell, Hawksworth, and Harold (2003) found that teachers in New Zealand were not convinced that they could make a difference to student outcomes, and that this is a major factor inhibiting change of practice in schools. When Wilkins (1999) surveyed PGCE (Post-graduate Certificate of Education) students' attitudes towards *good citizenship,* he found that younger student teachers, in particular, felt that politics were irrelevant to their daily life,

and that there was no prospect of political action affecting their lives. Can we expect teachers to engage in a science education that raises the socio-scientific awareness of their students, if the teachers themselves doubt their ability to make an impact on pupils' and are sceptical about the benefits of preparing them for a politically aware form of citizenship? Another source of inertia may be students themselves, because "they too, have expectations of science lessons and sometimes act to restore the familiar when teachers attempt radical change" (Hodson, 1999, p. 790).

When science education first became part of the curriculum in UK, public schools and emerging grammar schools were equipped with teaching laboratories. They were modelled on those being used in universities, and the practical work that took place in them was based on the university experiences of the teachers, rather than the needs and interests of the students (Nott, 1997). This early association between science education and laboratories as teaching spaces had an impact on the way that science was taught and perceived. This association still has influence on today's debate about the nature of the science that should be taught in schools (Jenkins, 2000). The traditional laboratory environment, in which most science is taught, may have a profound influence on pupils' understanding and perception of science (Elliott, 2000), just as the way scientists are portrayed in the media can (Schibeci & Lee, 2003). If the way in which science is taught is to change, then it may be necessary to change the environment in which it is taught.

Traditional teaching accommodation may be an additional factor limiting curricular reform. Secondary schools, in much of the developed and developing world, aim to provide sufficient laboratories for most science lessons to take place there. This involves a huge commitment of space and money. It is not surprising, therefore, that science teachers are largely unquestioning about the need to provide their pupils with a rich diet of practically-based activities and to justify doing so. However, plenty of science educationalists expressed their disquiet with this state of affairs (Osborne, 1997; Woolnough, 1997), arguing that preoccupation with practical science can distract attention from pedagogical techniques that may be more effective at promoting cognitive development, student motivation, and an understanding of socio-scientific issues.

A Curriculum to Meet All Needs?

Is it possible to design a form of science education that can provide all pupils with the attributes of scientific literacy, such as, an appreciation of how science works and an ability to assess the worth of evidence, while at the same time, preparing a minority of students for further study of science and work in science-dependent environments? Is it possible to give students more control over their work and give them choices? Can we find a way of involving students in the community as part of their science education, to make clear the link between the scientific way of approaching problems and the world they live in? The influential report sponsored by the Royal Society, "Beyond 2000" (Millar & Osborne, 1998) felt that this should be possible, but that "the science curriculum needs to differentiate more explicitly between those elements designed to enhance 'scientific literacy' and those designed as the early stages of a specialist training in science, so that the requirement for the latter does not come to distort the former" (p. 10). Levinson

and Turner (2001) see curricular reform at the centre of change, but insist that changes to assessment must also occur so that "social, ethical, and legal implications of the science should be integrated into the curriculum where possible, and formal assessment criteria should be devised to give recognition both to discursive argument and knowledge of science" (p. 22). In response to the calls for a curriculum that will better meet the needs of all, while still preparing the next generation of scientists, a new set of criteria for Key Stage 4 science were developed. The awarding bodies were instructed by the Qualifications and Curriculum Council (QCA) to develop new course specifications to meet these criteria, ready for launch in September 2006.

The QCA (see website) criteria require that the specifications should include a rationale reflecting an approach that places an emphasis on *one or more* (author's italics) of:

- evaluating evidence and the implications of science for society;
- explaining, theorising, and modelling in science;
- procedural and technical knowledge of science practice.

Further, it specifies that science courses should consist of the skills, knowledge, and understanding of how science works. These requirements are clearly a response to the scientific literacy movement, although it should be noted that the emphasis on more than one of the approaches is optional, so it is possible for the specifications to ignore *"the implications for society."* However, the detailed QCA criteria specify that "there are some questions that science cannot currently answer, and some that science cannot address; this represents a move away from a curriculum that at times implies that all scientific problems have been solved. This welcome reform introduces the concept of science as tentative and as a discipline that contributes to society, but that does not answer all questions posed by humankind.

Very clear statements in the QCA (2005) criteria refer to the socio-scientific issues that students should study as part of their science education:

a) the use of contemporary scientific and technological developments and their benefits, drawbacks, and risks
b) how and why decisions about science and technology are made, including those that raise ethical issues, and about the social, economic, and environmental effects of such decisions
c) how uncertainties in scientific knowledge and scientific ideas change over time, and the role of the scientific community in validating these changes.

One response to the instruction to devise a reformed GCSE (General Certificate of Secondary Education) programme was led by the University of York Science Education Group in collaboration with the OCR awarding body (Twenty First Century Science website). This specification, called *Twenty First Century Science,* requires all students to study a common core course leading to a single GCSE award, that 'aims to enhance students' scientific literacy and lead to better public understanding of science' (QCA website). It is designed to enable all students to:

- recognise the impact of science and technology on everyday life
- take informed personal decisions about issues that involve science

- understand the key points of media reports and reflect on the information included.

Course content has been selected to provide students with a broad understanding of scientific concepts with which to make sense of the world. However, the amount of scientific content has been reduced, with the intention of allowing the time needed to reflect on the nature of scientific knowledge.

In addition to this core, *scientific literacy* course, students will be able to select an additional single GCSE course that will provide the subject knowledge necessary for them to continue their studies of science. They will do this by choosing one of two options: *Additional Science* is aimed at enabling successful students to progress to advanced level science courses, and *Applied Science* will cater for students who envisage moving into science-related work environments after completing compulsory schooling. Thus, the programme appears to provide some of the flexibility Leach (2002) found teachers calling for, in Key Stage 4 science provision.

Time will tell whether the newly devised specifications can achieve what is intended. Critical factors determining their success are likely to include the enthusiasm with which teachers greet the programmes and the ability of those responsible for delivering the course to make the shift in pedagogical philosophy necessary.

Winning Teachers' Hearts and Minds

The type of radical change required in science education poses major problems, but there are some possible solutions. The hearts and minds of science teachers and intending science teachers need to be won, so that they might share a common vision of science, feel empowered to make a difference as individuals, and feel supported in their efforts. The Science Strategy in England (see website) is one attempt to do this. Having identified problems in the way that science was being taught to 11-14 year olds, a national strategy was implemented with the aim of bringing about change. An important part of the strategy is to promote teacher participation in, and ownership of, change. Teachers are encouraged and enabled to think critically about their teaching, while being exposed to alternative paradigms. Schools that have embraced involvement in the strategy may succeed in promoting change. However, it would be ironic if a vision of science education was promoted in which students develop their abilities to think independently and critically, and to take control of their work, while science teachers were thwarted in their attempts to apply the same qualities to their own teaching. Although continuing professional development opportunities, like those offered by the Strategy, may well have a part to play in the reform of science teaching, it is crucial that it does not rely on the *cascade* model, in which the only source of training for most teachers is the second-hand experience of a colleague. This approach may work when what is being shared is a simple technique or task, but it will not do as a way to change basic attitudes and perceptions.

Hodson, (2003) recommended fostering change from within the teaching profession by using action research in curriculum evaluation, and continuous appraisal and revision. This approach would need to be accompanied by community involvement to convince the public of the desirability of establishing a science curriculum that promotes socio-political action. Involving teachers in

action research may well be a useful strategy for promoting a change in perception.

A majority of new teachers recruited in England are recent graduates. Wilkins (1999) explored the attitudes of new recruits to aspects of citizenship and found that a small minority held views incompatible with a pluralist, tolerant society. It is reasonable to assume that a significant proportion would also hold views of science education that would make it difficult to prepare them to teach in a way that placed scientific literacy or science for citizenship as its central goal. To achieve the necessary changes in perception, there needs to be a paradigm shift in initial teacher training, away from the reductionist, competence-based model that has been imposed in recent years, towards one in which student teachers have the time to explore the purpose of science education in more depth, and develop their own ideas through independent thinking. This may mean that more time and resources need to be allocated to the process, with the aim of giving new teachers confidence in their ability to make a difference to pupils' lives.

The environment in which pupils learn about science may have a significant influence. If the ideas in science education are completely subjugated by the need for work benches, high stools, sinks and gas supplies, this may be partly responsible for the inability of many students to see the relevance of science to their lives. A more imaginative approach to the design of science teaching spaces is needed, to create versatile, comfortable classrooms in which practical activity can take place, but which are also more conducive to discussion and collaborative working. We should not even underestimate the likely educational advantages of providing students with more comfortable seating than traditional, backless, stools!

We should consider the experience of science that future teachers receive during their own education. Reform of the curriculum will be supported, or even promoted, by new teachers if their experience of science includes:

- sufficient opportunities to take control of their own work and make choices;
- opportunities to work with the community and in social, participatory environments;
- a consideration of the relevance of the subject to sustainable development;
- study of the communication of science.

A substantial minority of science graduates enter the teaching profession and, thus, become the first scientists that most young people encounter. If school students are to gain a favourable first impression of science and go on to maintain a lifelong engagement with it, then the inclusion of teaching techniques that mirror good practice in the school sector, and provision of courses that raise awareness of sustainable development and science communication, seem like a small price for university science departments to pay. University science departments should be encouraged to make these experiences the norm. We need new teachers who are themselves scientifically literate, who are aware of the concept of scientific literacy and who are keen to embrace the idea as part of their pedagogical philosophy.

The new science curriculum being introduced in England's schools is a response to the calls for science education to produce scientifically literate young people. The success of this curricular reform will, however, depend upon the

willingness and ability of thousands of teachers to embrace the new paradigm implicit in it. To promote such willingness and to foster the pedagogic abilities required will challenge those responsible for initial and continuing teacher education. However, it will also set out a series of challenges for a wider range of players. This will include those who design science teaching accommodation in schools, university science departments and society at large, all of whom will need to be persuaded of the need to change and of the benefits of change. However, the challenges facing us all are so great that we cannot afford to fail in this enterprise.

References

ATKIN, J. M., & HELMS, J. (1993). Getting serious about priorities in science education, *Studies in Science Education, 21*, 1-20.

BYBEE, R.W. (1997). Towards an understanding of scientific literacy. In W.Gräber and C. Bolte (Eds), *Scientific literacy.* Kiel, Germany: I.P.N.

DEBOER,G.E. (2000). Scientific literacy: another look at its historical and contemporary meanings and its relationship to science education reform. *Journal of Research in Science Teaching, 37*, 582-601.

DEPARTMENT FOR EDUCATION AND EMPLOYMENT/QUALIFICATIONS AND CURRICULUM AUTHORITY (1999). *Science: The national curriculum for England.*London:The Stationery Office.

Department for Education and Skills, Key Stage 3, Science Strategy: www.standards.dfes.gov.uk/keystage3/subjects/science/

ELLIOTT, P. (2000). The visual environment in which secondary science is taught, *School Science Review, 82*, 73-80.

FENSHAM, P. J., & HARLEN, W. (1999) School science and public understanding of science, *International Journal of Science Education, 21*, 755-763.

FENSHAM, P. J. (2004). Increasing the relevance of science and technology education for all students in the 21st century, *Science Education International, 15*, 7-26.

HODSON, D. (1999). Going beyond cultural pluralism: science education for sociopolitical action, *Science Education, 83*, 775-796.

HODSON, D. (2003). Time for action: science education for an alternative future, *International Journal of Science Education, 25*, 645-670.

HOUSE OF LORDS (2000). *Science and society. Science and technology select committee:, Third report.* UK Parliament.

HURD, P. D. (1958) Science literacy: its meaning for American schools. *Educational Leadership, 16*, 13-16

HURD, P. D. (1998). Scientific literacy: new minds for a challenging world. *Science Education, 82*, 407-416.

JENKINS, E. W. (2000). 'Science for all': time for a paradigm shift? In R. Miller, J. Leach and J. Osborne (Eds). *Improving science education: The contribution of research (pp. 207-226).* Buckingham: Open University Press.

KOLSTÖ, S. D. (2001). Scientific literacy for citizenship: Tools for dealing with the science dimension of controversial socio-scientific issues. *Science Education, 85*, 291-310.

LEACH, J. (2002). Teachers' views on the future of the secondary science curriculum. *School Science Review, 83,* 43-50.

LEVINSON, R. (2001). Should controversial issues in science be taught through the humanities? *School Science Review, 82,* 97-102.

LEVINSON, R., & TURNER, S. (2001). *Valuable lessons: engaging with the social context of science in schools.* London: The Wellcome Trust.

MCCURDY, R. (1958). Toward a population literate in science, *The Science Teacher, 25,* 366-368.

MILLAR, R. (1996). Towards a science curriculum for public understanding. *School Science Review, 77,* 7-18.

MILLAR, R., & OSBORNE, J. (1998) *Beyond 2000: Science education for the future* London: King's College.

MILLAR, R., & OSBORNE, J., & NOTT, M. (1998). Science education for the future, *School Science Review, 80,* 19-24.

MURPHY, C., BEGGS, J., HICKEY, I., O'MEARA, J., & SWEEBET, J. (2001). National Curriculum: Compulsory school science – is it improving science literacy? *Educational Research, 43,* 189-199.

NOTT, M. (1997). Keeping scientists in their place. *School Science Review, 78,* 49-60.

OSBORNE, J. (1997) Practical alternatives. *School Science Review, 78,* 61-66.

SCHIBECI, R. & LEE, L. (2003). Portrayals of science and scientists and 'Science for Citizenship', *Research in Science and Technological Education, 21,* 177-192.

Qualifications and Curriculum Authority, New GCSE criteria: www.qca.org.uk/11881.html

SCHREINER, C., & SJØBERG, S. (2003). Optimists or pessimists? How do young people relate to environmental challenges? *European Science Research Association,* conference proceedings, Noordwijk, Netherlands, 19-23 August.

SOLOMAN, J. (1997). School science and the future of scientific culture, In: R. Levinson and J. Thomas (Eds), *Science today: Problem or crisis?* (pp. 151-162). London: Routledge.

THRUPP, M., MANSELL, H., HAWKSWORTH, L., & HAROLD, B. (2003). 'Schools can make a difference' – but do teachers, heads and governors really agree? *Oxford Review of Education, 29,* 471-484.

Twenty First century Science: www.21stcenturyscience.org/

WILKINS, C. (1999). Making 'Good Citizens': the social and political attitudes of PGCE students, *Oxford Review of Education, 25(1 & 2),* 217-230.

WOOLNOUGH, B.E. (1997). Motivating students or teaching pure science? *School Science Review, 78,* 67-72.